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On the Connections Among
Activity Based Costing, Strategic
Optimization Models for Decision Support,
and the Resource-Based View of the Firm

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Introduction

The starting point for the developments presented in this paper are experiences on several projects in different firms in which **optimization models** were created and used to study strategic resource planning questions. In some instances, the models drew on **activity based costing (ABC)** relationships that the firms had implemented independently of the modeling exercises. In other instances, the model builders developed ad hoc ABC relationships to use as inputs to the models. Over time, the generality and importance of the connections between ABC and optimization modeling became much clearer.

Descriptions of resource availabilities, their costs, and their consumption by value adding activities were central constructs in effecting the linkages between ABC and optimization models. In most cases, the models initially sought to identify strategies for minimizing the total cost of meeting forecasted demand, mainly using existing resources. Invariably, though, issues arose about how to identify a comprehensive set of potential new strategic resources, and how these resources could be acquired and deployed to vary product mix so as to maximize net revenues. Resolving such issues in the construction and optimization of strategic planning models with greater scope was difficult. As we shall see, the emerging literature on the **resource-based view of the firm (RBV)** provides important insights for interpreting and expanding optimization models to address broader strategic questions.

Thus, we believe that there is important synergy among three disciplines, ABC, optimization models, and RBV, which have been viewed until now by both academics and practitioners as unconnected. Our primary objectives in examining these connections are:

1. To discuss state-of-the-art methods for creating and using **data driven** models, both descriptive and normative, for analyzing strategy within the firm; and,
2. To examine new modeling approaches for important areas of strategy formation that have not yet been widely analyzed by data driven models.

By data-driven models, we mean ABC and optimization models derived from corporate and external data bases. Artistry is required to aggregate and otherwise extract data from these transactional data bases to create effective strategic planning models. The aim is to blend model constructs relating to investments and other strategic options with constructs describing in a suitably aggregate manner the firm's operations under the various options. Space limitations do not permit further discussion of this important point (see Shapiro, Singhal and Wagner [1993]).

By contrast to ABC and optimization models, RBV has thus far produced only qualitative theories and insights. Nevertheless, as we discuss below, results from ABC

and optimization models can be viewed as quantitative mechanizations of RBV. Conversely, by translating concepts from RBV into ABC and optimization model elements, the scope of such models can be expanded in important new ways.

Our focus on quantitative analysis and data-driven models is not meant to imply that intuitive managerial judgments can or should be made irrelevant to the process of strategy formation. Rather, we believe that such judgments can profit greatly from analysis with models, especially in firms whose operations and markets are characterized by large numerical data bases. The central question is: In trying to extend managerial intuition, which aspects of strategy can usefully be measured, estimated, and analyzed by models?

Review of Concepts and Terms

We begin with a brief discussion of concepts and terminology. Since many articles and books have been written about each of the three disciplines, we will only review the main ideas and the meaning of key terms.

First, in order to focus our discussion, we will restrict ourselves to strategic planning issues arising in **supply chain management**. A company's supply chain is comprised of geographically distributed facilities such as plants, distribution centers, supplier warehouses, or retail outlets, and transportation links carrying products between facilities. The facilities may include physical entities operated by the company's suppliers and the company's customers as well as those operated by the company itself.

Thus, we will limit our attention to firms that manufacture and/or distribute physical products, and for which R&D activities are not a dominant aspect of their businesses. Included are retailing companies, food manufacturers, forest products companies, process manufacturers, and electric utilities. Strategic analysis of firms in the service industry, or those with extensive and complex R&D activities, such as pharmaceutical companies, will not be addressed although the approaches we will present are applicable to such firms in modified form.

A growing number of corporations are employing **ABC** methods to more accurately determine their supply chain costs. Cooper and Kaplan [1991] and Turney [1992] provide broad overviews of ABC methodologies; Pohlen and La Londe [1994] discuss their applications in logistics. ABC models achieve greater accuracy and provide superior insights by relating levels of value adding activities, called **cost drivers**, to the volumes of goods and services produced. For example, a product sustaining cost may be expressed as a linear function of the cost driver that is the volume of the product manufactured. Some costs, however, are not directly or linearly related to product volumes. A batch sustaining cost may be expressed as a function of the cost driver that is the number of times a machine is set-up to produce a particular family of products.

In a manufacturing firm, costs and cost drivers may usefully be broken down into a **cost hierarchy** comprised of facility sustaining, process sustaining, batch sustaining and product sustaining costs (Cooper and Kaplan [1991]). In short, the implementation of an ABC model involves a segmentation of the costs in the general ledger of a facility followed by a regression or curve fitting exercise that relates costs in each segment to their cost drivers. In addition to developing more accurate unit costs, ABC methods provide metrics and help identify non-value adding activities whose elimination can contribute to reducing total cost.

Optimization models refer to **mathematical programming models** that provide formal systems for analyzing managerial decisions (Winston [1995]). In this paper, we will be discussing three types of models:

- **linear programming models**, which identify effective resource allocation schemes;
- **mixed integer programming models**, which extend linear programming models to capture fixed (lumpy) investment and resource costs, locational decisions, economies of scale and non-numeric policy constraints; and
- **stochastic programming models**, which extend both linear and mixed integer programming in explicitly addressing uncertainties associated with the future to identify optimal contingency plans and hedging strategies for the firm (e.g., see Bienstock and Shapiro [1988]).

Linear programming models are the cornerstone of mathematical programming because they can be easily optimized and because linear programming approximations are used to optimize more complex models. Economic interpretations of linear programming also provide qualitative insights into resource allocation processes in the firm.

The premises underlying linear programming models, such as assumptions that all cost and resource utilization relationships are linear and infinitely divisible, are too simplistic. Mixed integer programming extensions provide much more realistic descriptions of supply chain management problems. Such models use zero-one integer decision variables to describe more accurate cost and resource relationships, and to capture locational decisions. The added realism comes at a cost, however, because mixed integer programming models must be optimized as a series of linear programming approximations. Despite their computational complexity, mixed integer programming models provide a practical and powerful method for evaluating supply chains (e.g., see Shapiro [1992], Shapiro, Singhal and Wagner [1993], Arntzen et al [1995]).

Stochastic programming combines probabilistic decision trees with linear and mixed integer programming models in providing models that explicitly evaluate resource planning in the face of uncertainty. Such models offer an enticing paradigm for strategy analysis in the firm that is beyond, but not by too far, the current state-of-the-art. Our aim in discussing them here is to promote their application.

RBV is a recently articulated theory that is still under development. Our review of the theory is based on Peteraf [1993] who provides an extensive bibliography; see also Wernerfelt [1984], Barney [1991], and Conner [1991]. Its philosophy is that a firm's sustainable competitive advantage depends heavily on its resources and how they are used. In particular, the theory assumes that superior firms possess **heterogeneous** resources that differentiate them from other firms and allow them to earn rents; that is, the marginal costs of their products, which equal the market prices they receive, exceed their average costs. The rents are converted to sustainable profits because there are forces which limit competition for critical resources, once the industry has recognized their value.

Two factors limiting competition are **imperfect imitability** and **imperfect substitutability** of heterogeneous resources. These factors exist when there are barriers due to patents, contracts, learning effects, or market preferences that make imitation and substitution by other firms difficult or impossible. Moreover, critical resources of the superior firm will be **perfectly immobile**, which means they are idiosyncratic and have

no use in other firms, or **imperfectly mobile**, which means they can be traded but have higher value within the firm. Finally, the theory states that a firm can establish heterogeneous new resources only if there are limits to competition prior to efforts on the part of the firm to create them. Otherwise, the rents that the superior firm can realize will be dissipated by excessive costs of initial competition.

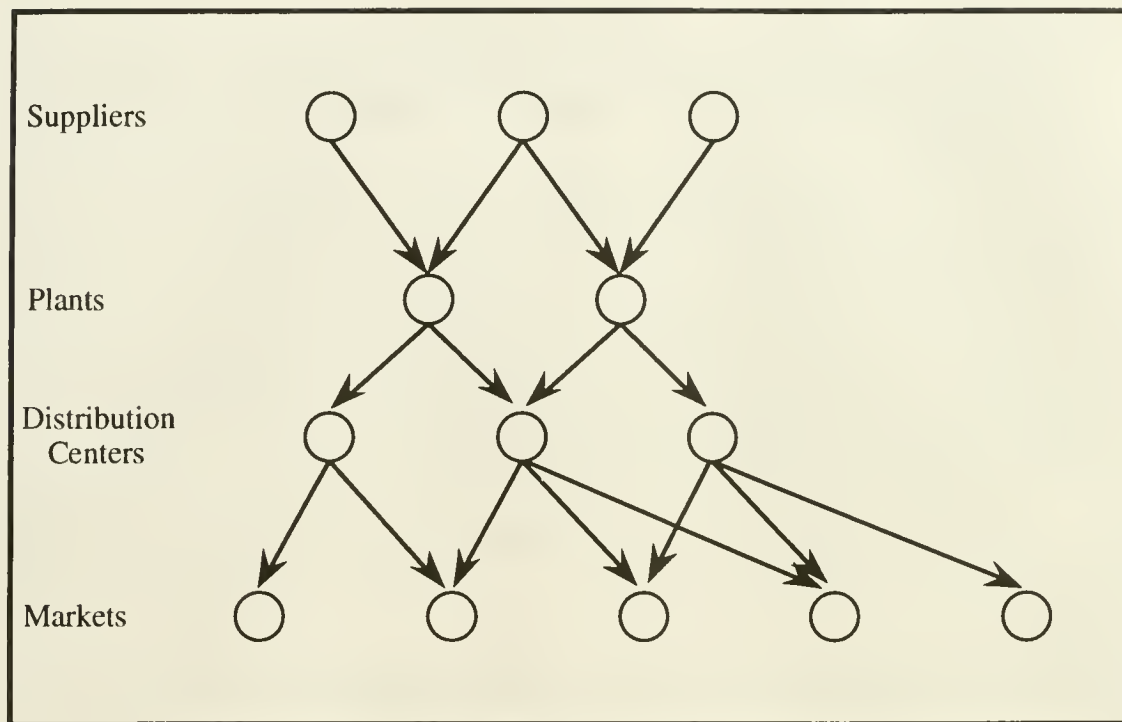
The concept of a firm's **core competencies** is an important idea linked to RBV (Prahalad and Hamel [1990]). Core competencies refer to those heterogeneous resources that provide the superior firm with sustainable competitive advantage. Often, senior managers in a firm do not understand the precise nature of its core competencies, how they should be protected, and how new ones should be created. One of the objectives of this paper is to suggest new methods for identifying and quantifying core competencies, at least in part, by ABC and optimization models.

Extending ABC Models to Optimization Models

ABC models can be extended in natural ways to optimization models for analyzing a firm's supply chain strategy. To put the extensions in perspective, we begin our discussion by depicting the supply chain as a **network** comprised of **nodes**, which correspond to facilities where products are acquired, transformed, stored and sold, and **arcs**, which correspond to directed links between facilities along which products flow. Here products refer to raw materials, parts, components, intermediate products, and finished products. A network representation of a typical supply chain is displayed in Figure 1.

Obviously, Figure 1 is a very high level depiction of the firm's supply chain. In implementing an optimization model, we must zoom in on each node to capture details describing the facility's operations. Modeling such details is precisely where we effect the connections between ABC and optimization models. On the one hand, ABC practitioners have developed cost hierarchies and other modeling approaches describing facility costs and operations that are useful in creating decision models. On the other hand, extensions are necessary and important because, although ABC has been extolled as a valuable tool for decision support, it cannot address fundamental questions such as

- What are optimal levels for the firm's resources at each of its facilities over the firm's medium term and long term planning horizons?
- How should these resources be allocated to production activities at each facility so as to minimize total supply chain cost, or maximize net revenues if product mix is allowed to vary?
- Which products should be manufactured and which production transformation activities should be employed at each facility to minimize total cost or maximize net revenues?



Supply Chain Network
Figure 1

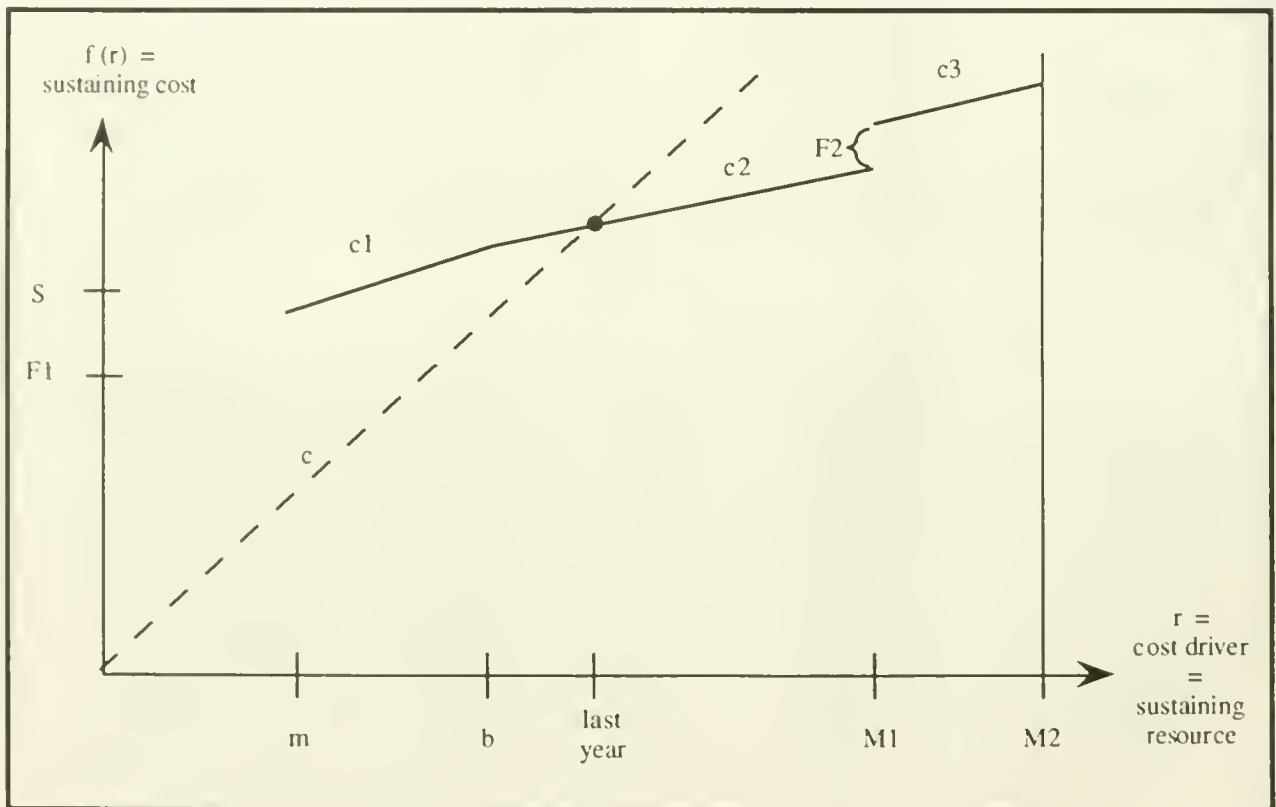
ABC cost descriptions of the firm's operations at each facility must be extended to address questions such as those just posed, and others. Their extension begins with the recognition that costing rates and activity costs developed by ABC are based on historical values for the costs and cost drivers. Since these values will change in the future, we must extend the relationships to forecast how costs will vary as **functions** of the cost drivers. In developing such functions, we distinguish between those for which the cost driver is a resource that may be scarce and therefore may constrain an optimal strategy, and those for which the cost driver is merely an accounting device and not a resource that will constrain the strategy. We refer to the former functions as **cost/resource functions**, and to the latter as **cost/accounting functions**. Resources in the former category will be called **sustaining resources** while resources in the latter category will be called **accounting resources**.

Figure 2 depicts a typical cost/resource function for a given period of operations (e.g., one year). For example, it might refer to machine hours as a cost driver on equipment used in making several products. In this case, machine hours would be treated as a process sustaining resource.

The parameters describing the cost/resource function are:

- A fixed cost $F1$ associated with using the resource at any level;
- A shut-down cost S associated with a zero level of resource utilization;

- A conditional minimum level m of resource utilization above which it must be if it is not zero;
- A break point of b above which the variable cost measured in dollars per hour decreases ($c_2 < c_1$);
- A maximal level of resource utilization of M_1 possible during the period if additional resource is not acquired;
- A fixed cost F_2 associated with acquiring additional resources for use during the period;
- A variable cost in dollars per hour of c_3 ($c_3 > c_1$) for using the new resource up to a total maximal level of M_2 possible during the period.

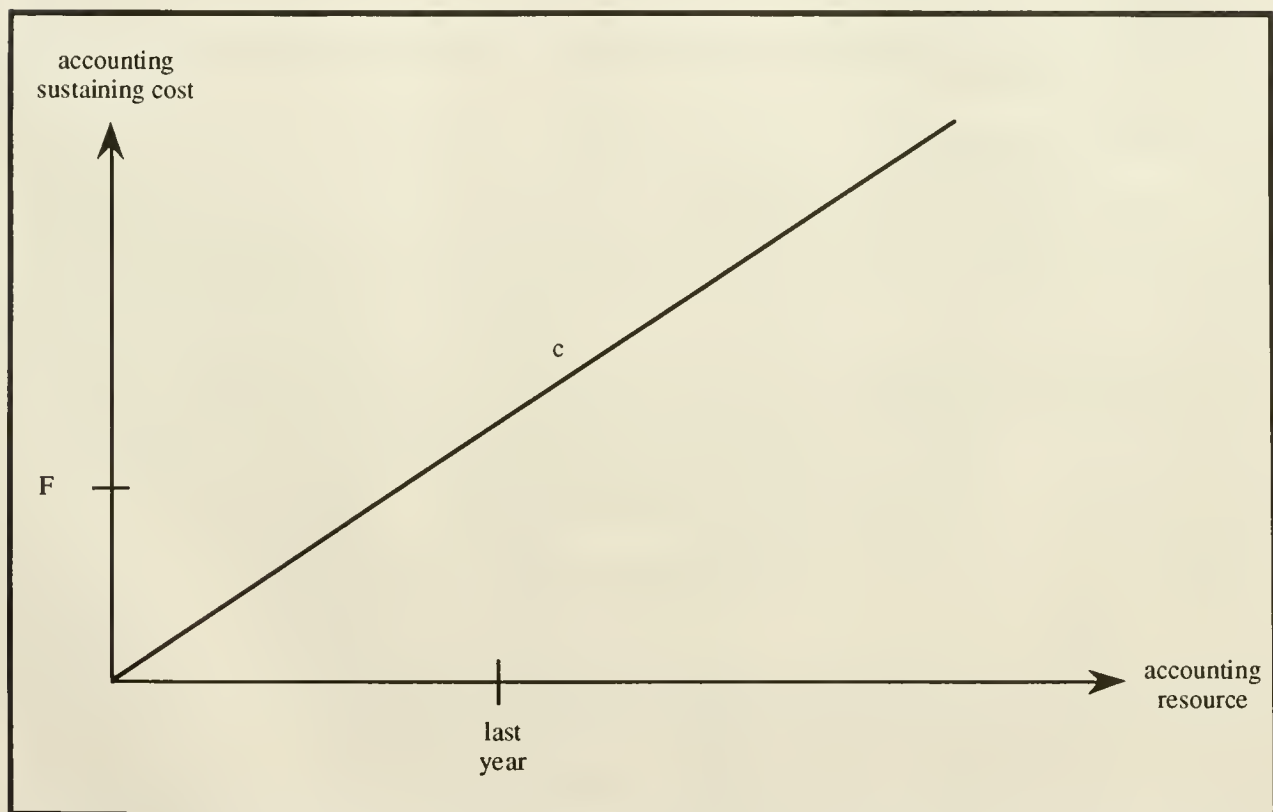


Cost/Resource Function
Figure 2

Figure 2 is only representative of the many cost/resource functions we might develop to analyze a firm's supply chain decisions. For example, the number of changes in unit cost as well as the number of increments of resource addition with fixed costs can be arbitrary. Mixed integer programming modeling constructs can be used to capture the nonlinearities and discontinuities.

Note that we have also displayed last year's resource level and the traditional accounting rate of c dollars per hour based on it. The dotted line in the figure clearly shows that the projected sustaining cost will be inaccurate, even when the cost driver is an appropriate one.

The partition of cost drivers into sustaining resources and accounting resources is a judgment made by the modeling practitioner based on his/her knowledge of the firm. Although it would be safe to treat all cost drivers as potentially scarce resources, more parsimonious models will result if cost drivers that almost certainly will never be constrained by physical, human, or financial resources be treated as accounting resources. For example, the number of orders taken in a year by telephone salespeople may be a meaningful cost driver for describing sales department costs, but unless the firm's volume of business doubles, which we consider to be highly unlikely, this number will not be constrained by physical limitations. Moreover, assuming a significant number of additional sales people can be hired at a constant cost rate, the firm will not encounter human constraints to its order taking and other sales activities. This relationship is displayed in Figure 3.



Cost/Accounting Function
Figure 3

The major step in extending ABC relationships to an optimization model is to describe the interactions of transformation activities at facilities with cost/resource and cost/accounting functions, and with other relationships describing the constraints and strategy options of the firm. We illustrate such a construction with an example of a facility sub-model. A complete supply chain model consists of multiple facility sub-models along with supplier and market sub-models, plus transportation sub-models comprised of arcs linking suppliers to facilities, facilities to other facilities, and facilities to customers.

First, we must define indices, parameters and functions and decision variables:

Indices

$s \in S$: suppliers of raw materials

$i \in I$: raw materials

$j \in J$: transformation activities

$k \in K_1$: accounting resources

$k \in K_2$: sustaining resources

$k \in K_3$: fixed resources

$k \in K_4$: design and policy constraints

$p \in P$: output products

Parameters and Functions

a_{ij} = rate at which activity j consumes raw material i

a_{kj} = rate at which activity j consumes resource k

a_{pj} = rate at which activity j produces output product p

r_k = fixed level of resource k ($k \in K_3$)

L_j = upper bound on activity j

c_j = product sustaining unit cost

u_k = process and facility resource accounting unit cost ($k \in K_1$)

$f_k(r_k)$ = function describing the cost of the sustaining resource r_k ($k \in K_2$)

Decision Variables

w_{si}	=	quantity of raw material i to be acquired by facility from supplier s
r_k	=	utilization of resource k
x_j	=	level of activity j
y_{pm}	=	quantity of output of product p to be shipped from facility to market m

The above parameters, functions and variables are used to construct the following:

Facility Sub-Model

$$\sum_j a_{ij} x_j - \sum_s w_{si} = 0, i \in I \quad \text{raw material balance equations} \quad (1)$$

$$\sum_j a_{kj} x_j - r_k = 0, k \in K_1 \quad \text{accounting resource balances} \quad (2)$$

$$\sum_j a_{kj} x_j - r_k \leq 0, k \in K_2 \quad \text{sustaining resource constraints} \quad (3)$$

$$\sum_j a_{kj} x_j \leq r_k, k \in K_3 \quad \text{fixed resource constraints} \quad (4)$$

$$\sum_j a_{kj} x_j \leq b_k, k \in K_4 \quad \text{design and policy constraints} \quad (5)$$

$$-\sum_j a_{pj} x_j + \sum_{m \in M} y_{pm} = 0, p \in P \quad \text{output product balance equations} \quad (6)$$

$$x_j \leq L_j, j \in J \quad \text{production bounds} \quad (7)$$

Objective Function Costs to be Minimized

$$\sum_j c_j x_j \quad \text{product sustaining costs} \quad (8)$$

$$+ \sum_{k \in K_1} u_k r_k \quad \text{process and facility accounting resource costs} \quad (9)$$

$$+ \sum_{k \in K_2} f_k(r_k) \quad \text{process and facility sustaining resource costs} \quad (10)$$

The system of equations and inequalities (1) to (7) of the facility sub-model, along with other constraints and relationships describing activities at other facilities and flows between facilities, determine the optimal levels of the production activity variables x_j at the facility, along with optimal levels of the raw material, resource and product output variables. The product activity variables determine the associated product sustaining costs by (8). The raw material balance equations (1) describe how the transformation activities consume raw materials. The output product balance equations (6) describe how product output shipped to the markets m equals that produced at the plant. Note that in this strategic, snapshot model, inventories do not enter into the decision making process.

The accounting balances (2) mechanize cost/accounting functions by computing the levels of the cost drivers r_k which are costed at the rates u_k in (9). The sustaining resource constraints (3) mechanize the cost/resource functions by determining the optimal levels of the sustaining resources whose costs are determined by the functions $f_k(r_k)$ in the sums in (10). These constraints may not be binding in the sense that the sum of the activity levels may be strictly less the resource level. The functions $f_k(r_k)$ have a form similar to the one depicted in Figure 2. Mixed integer programming modeling constructs are used to represent the nonlinear and discontinuous forms of these functions; we omit details here.

The resource $k \in K_2$ is a facility sustaining resource if all, or at least most, of the coefficients a_{kj} in constraint (3) are positive. By contrast, the resource $k \in K_2$ is a process sustaining resource if only a limited number of the coefficients a_{kj} in constraint (3) are non-zero (i.e., positive). In short, the distinction between facility and process sustaining resources and costs may be ambiguous and ultimately depend on human judgment.

The fixed resource constraints (4) correspond to resources at the facility that cannot be varied and whose costs are sunk. The extent to which such costs are sunk depends in large part on the planning horizon of the model. For example, a labor resource dictated by a union contract for a fixed number of hours for next year would be treated as a fixed resource with a sunk cost in a model of next year's plans. Over the longer term, this resource would not be viewed as fixed.

The design and policy constraints (5) refer to constraints on production that do not involve resources; in many instances b_k will be zero on such constraints. Blending constraints at an oil refinery are atypical design constraint. A constraint stating that the facility must product at least as much as one product group as it does of a second product group is an example of a policy constraint.

Applications in Specific Firms

In this section, we review recent implementations and applications of ABC and optimization models to the strategic analysis of supply chains in three companies:

- A multi-national food manufacturer
- A specialty chemicals company
- A wholesaling/retailing company

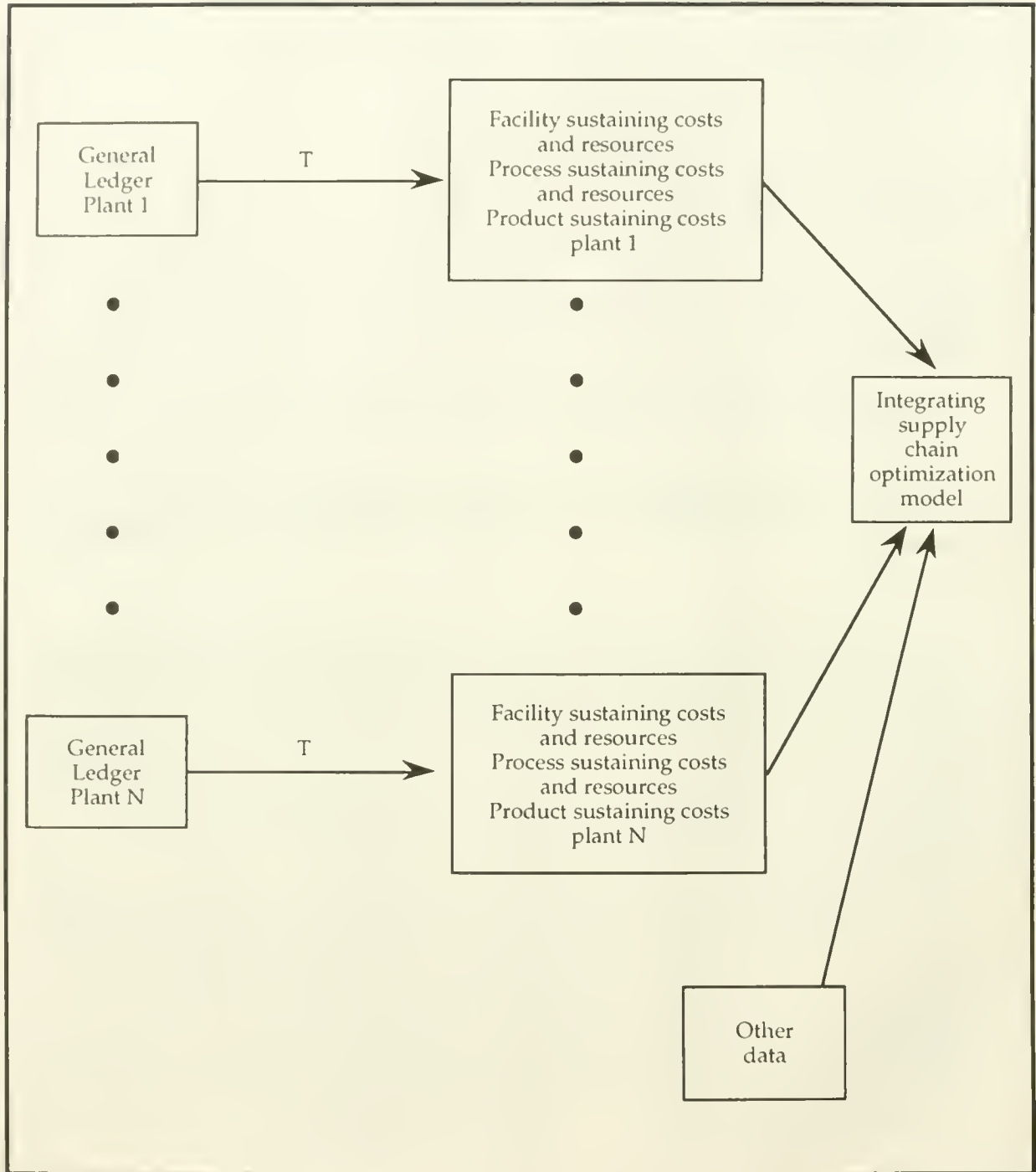
Multi-national food manufacturer

This company has more than 15 plants in the US, Canada and Mexico. Following passage of NAFTA, senior management engaged a team of external consultants to implement an optimization model for studying consolidation of their sourcing, manufacturing and distribution supply chain. Two major reasons for performing the study were:

- For some time, the company had been operating under conditions of excess capacity among their manufacturing facilities;
- Passage of NAFTA eliminated or greatly reduced tariffs and import/export restrictions between countries thereby making it economically feasible to manufacture most products in fewer locations and, where appropriate, ship them across national boundaries.

A major task of the project was the development of compatible cost and resource descriptions of the company's plants. As shown in Figure 4, each of the plants had its own, locally developed general ledger of accounts which required translation into product, process and facility sustaining cost/resource functions of the type discussed in the previous section. The ABC modeling process served to homogenize the disparate accounting schemes at the various plants in constructing cost/resource functions that could be compared across plants. This task was the most difficult one of the project. In the final analysis, the consulting team was successful in developing general procedures and programs, the template T, for mapping any plant's general ledger into its cost/resource functions.

ABC models were useful in providing metrics contrasting facility, process and product sustaining costs among the plants. The integrating optimization model played a critical role, however, in deciding on optimal resource levels for each plant and the quantities of individual products to be manufactured there. The objective driving the evaluation was to minimize the total delivered cost of all products to meet projected demand in the study years. In other words, metrics about production costs at individual plants could not determine an optimal supply chain strategy because they could not decide optimal resource levels, and could not account for plant locations relative to geographically dispersed markets.



ABC Models Feed Supply Chain Optimization Model
Figure 4

The supply chain optimization model was successfully validated and then run under a number of scenarios to assess potential consolidation strategies. Cost savings of more than 10% on avoidable costs exceeding \$100 Million were identified. The company intends to continue using the ABC and supply chain optimization models after the study has been completed. Their strategic plans will require frequent adjustment in response to external factors. Ironically, but probably not coincidentally, increasing volatility of exchange rates became a big issue after NAFTA was passed and the project begun, not just between the US dollar and the Mexican peso but also between the US dollar and the Canadian dollar.

Specialty chemicals company

This company supplies a range of specialty chemicals products to worldwide markets. It also has manufacturing facilities around the world, with movement of intermediate products among plants as well as movement of finished products to the markets. Capital investments in process manufacturing equipment and manufacturing operating costs, are high and represent a large percentage of the total cost of the products.

Given the complexity of their operations and the growth of markets for new products, senior management engaged a consulting team to implement an advanced decision support system based on optimization models to assist in evaluating their strategic plans. The models address

- Sourcing costs and constraints
- In-bound transportation costs and constraints on links between sources and plants
- Product, process and facility sustaining costs and resources at manufacturing plants
- Multi-stage processes and transformation recipes at the plants
- Inter-facility product transfers
- Out-bound transportation costs and capacities on links between plants and markets

The models may be optimized so as to minimize total supply chain costs or to maximize total supply chain net revenues. They are being used to evaluate global asset utilization, raw material sourcing strategies, and global production/distribution strategies.

For the purposes of our discussion here, an important aspect of the project was, and continues to be, an accurate mapping of manufacturing costs into product, process and facility sustaining cost/resource functions. Formal application of ABC methods to this task is new to the company and was stimulated by the model development project. ABC representations that accurately reflect economies of scale in manufacturing, particularly as they relate to specific processes, are crucial in determining effective strategies via the optimization model.

In addition, the company must develop cost and resource utilization data for potential new products to assess their profitabilities from a global supply chain viewpoint. Unlike traditional ABC analyses that draw on historical data, the data for new products require extrapolation of data about relevant existing products. Moreover, learning associated with the manufacture of new products needs to be quantified and incorporated in the models.

Wholesaling/retailing company

This wholesaling company buys and distributes consumer products to approximately 500 franchised, retailing outlets throughout Canada. Originally, it had 7 distribution centers (DC's) of various sizes, locations, and missions. The number of different SKU's sold in a year exceeds 50,000.

Although profits remained healthy, senior management decided about two years ago to re-engineer the wholesaling company, largely because they could see increasing competition in many of their markets just over the horizon. The goals of re-engineering were

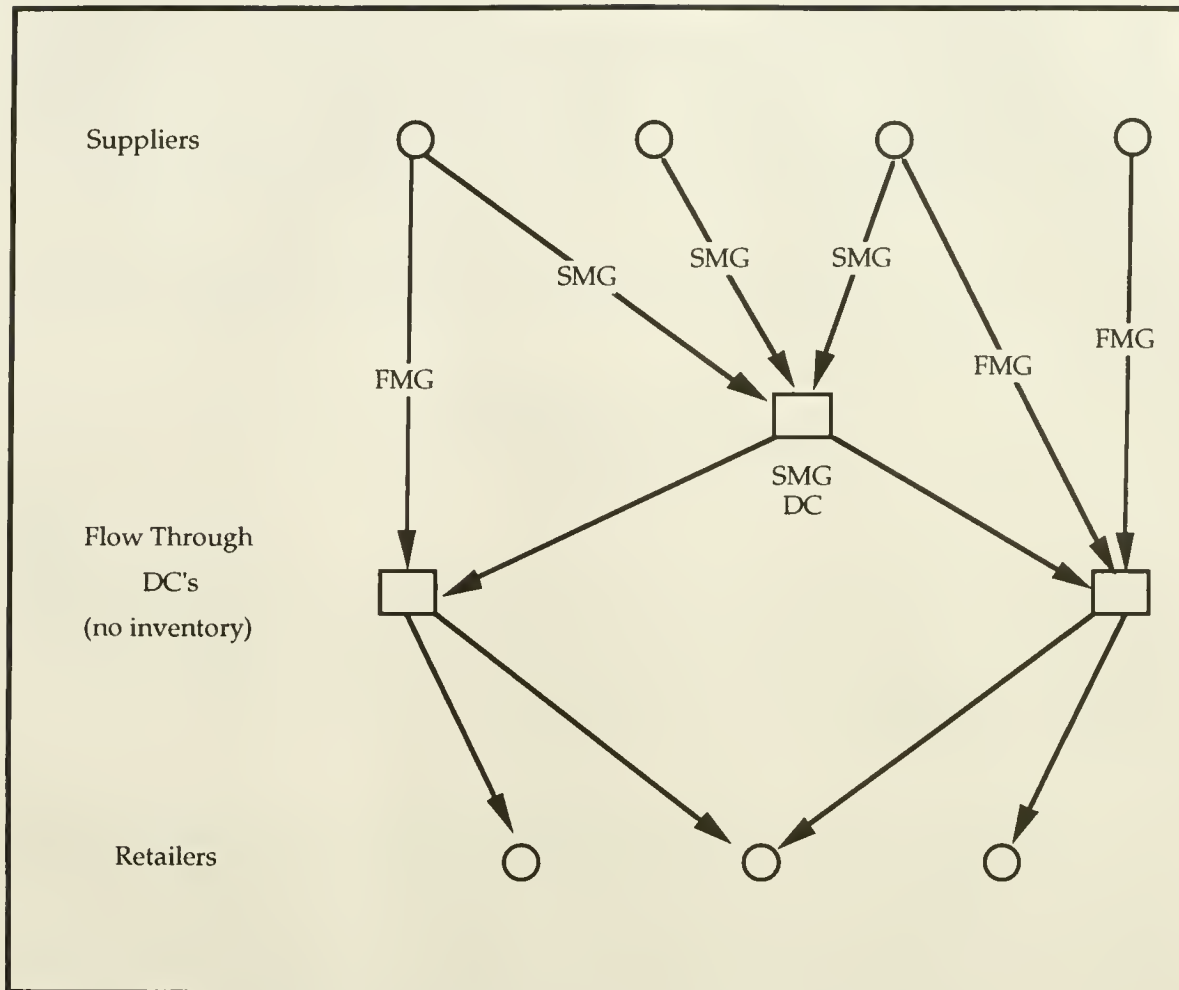
- To improve the cost effectiveness of transportation, warehousing and inventory management practices;
- Working with the retailers, to develop more effective purchasing and product replenishment processes;
- To implement new operational procedures exploiting point of sales information, electronic data interchange arrangements with suppliers, and other information technology advances.

To address the first goal, the company acquired off-the-shelf software for supply chain modeling, and assembled a team of internal consultants to develop the decision data base from which the models would be constructed.

Although the wholesaling company is not involved in manufacturing products, there is a form of "production" at the DC's. Products arriving there from many suppliers are received, sorted, sometimes stored, sometimes assembled, and then dispatched. The internal consultants used ABC methods to identify product, process sustaining and facility sustaining costs, cost drivers and resource functions based on these "production" activities. They also developed new information to forecast the costs and resource requirements of potential new operating procedures to be evaluated by the supply chain model.

For example, the product line was divided into fast moving goods (FMG) and slow moving goods (SMG). As shown in Figure 5, the model was used to study the economics of using flow-through equipment to handle FMG while centralizing the storage of SMG in a single DC. With this scheme, suppliers package FMG with bar codes indicating their final store destinations. Equipment at the flow-through DC reads the codes and automatically sorts the FMG into full truckload shipments to individual stores. If managed properly, this type of operation can achieve considerable cost savings by eliminating handling and inventories of FMG. In addition, SMG are stored in a single DC, thereby reducing their inventory holding costs by a significant amount. Store initiated orders for SMG are handled by the SMG DC as a flow-through supplier.

The company has used the optimization modeling system to great advantage in identifying more effective supply chain configurations and in simulating the impact of new procedures on their operations before committing to the time and expense of implementing them. The models sometimes indicated supply chain strategies that, at first, seemed counter intuitive, but upon further study, proved themselves to be meritorious.



Inventory Management of Fast vs. Slow Moving Goods

Connections Between Data Driven Models and the Resource Based View of the Firm

The data driven models for analyzing supply chain strategies that we just discussed focused heavily on resource planning. Since the central premise of RBV is that the firm's competitive advantage stems in large part from its ownership and utilization of heterogeneous resources, we are naturally drawn to ask:

What information can data driven models of a firm's supply chain provide about the heterogeneity of the firm's resources?

Wernerfelt [1994] confirms that measurement methods such as these that map the space of resources are needed to make RBV more useful.

To answer this question, we exploit marginal cost information provided by optimization algorithms that solve the supply chain models. Specifically, by fixing all zero-one variables in a mixed integer programming model of the firm's supply chain at their optimal values and solving the residual linear programming model, we can compute optimal **shadow prices** on all resource constraints. Depending on the objective function driving the model, these shadow prices measure the decrease in minimal cost, or increase in maximal net revenues, that would occur if another unit of resource were available. They need not be unique, but we can treat this ambiguity as of secondary importance.

As shown in Figure 6, relative to an optimal supply chain strategy and industry average unit costs for a resource, we have posited five categories into which the resource may fall:

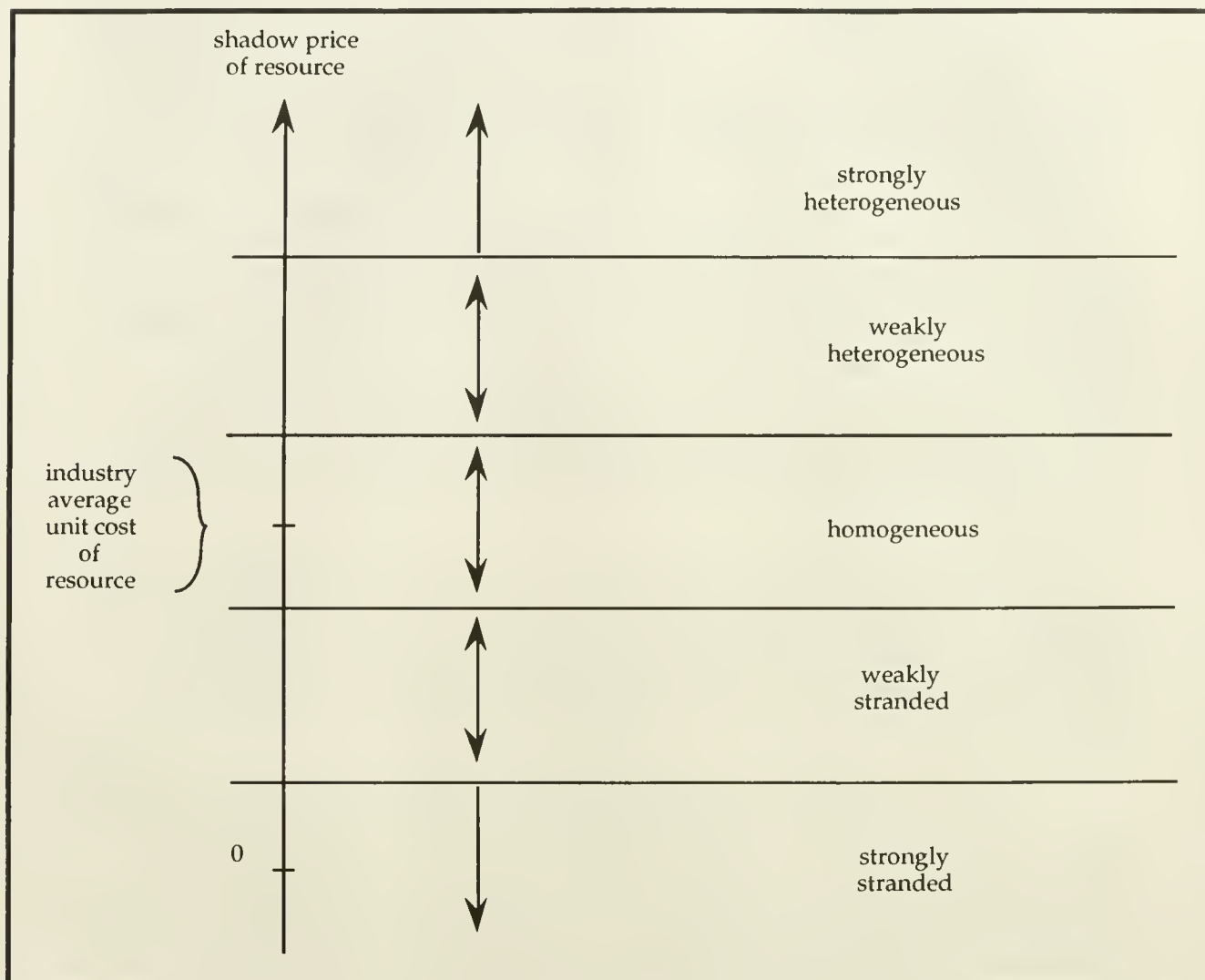
- strongly heterogeneous
- weakly heterogeneous
- homogeneous
- weakly stranded
- strongly stranded

If the resource is unique to the firm and no meaningful industry average unit cost exists, then the Figure simplifies to two ranges: Heterogeneous if the shadow price is positive and stranded if the price is non-positive. Moreover, a cost/accounting function, such as the one depicted in Figure 3, corresponds only to a homogeneous resource for which perfect markets allow expansion or contraction, virtually without limit, at approximately the industry average unit cost of the resource.

We elaborate briefly on this taxonomy with examples. Consider the cost/resource function in Figure 2 that may describe a heterogeneous, homogeneous or stranded resource for which expansion and contraction is to be considered. Suppose the resource corresponds to hours of skilled labor used to manufacture many products in a net revenue maximizing model. Suppose further that the resource achieves the upper bound M2 in an optimal solution. We consider this to be a hard upper bound in that the firm cannot acquire additional resources of this type, at least not without prohibitive expense, within the scope of the model. Suppose still further that the shadow price is ten times greater than the hourly compensation of the skilled employees. One could then justifiably view the resource as strongly heterogeneous.

An option for stretching strongly heterogeneous resources is for the firm to outsource the manufacture of components or parts using these resources. This will free up the firm's use of the resources in other value adding activities. Such **make-or-buy** decisions can be evaluated by supply chain models (see Shapiro [1994] for an example).

On the other hand, if the resource lies strictly between m and $M1$ or $M1$ and $M2$ in an optimal solution, mathematical analysis shows that the shadow price will always lie between $c2$ and $c3$ (recall that $c2 < c1 < c3$). Assuming this range is small and straddles the industry average, the resource can be considered homogeneous. If future conditions should change, such as an increase in raw materials without an increase in product sales price for products using the resource, the firm might find it wishes to reduce the quantity it makes of these products and thereby reduce its use of this resource.



Resource Categories
Figure 6

Finally, if the optimal resource level equals the conditional minimum m , this resource might well have a shadow price significantly below the industry average, including the possibility that it is negative, which indicates that the resource is weakly or strongly stranded. The need for the firm to decrease or eliminate its holdings of stranded resources has been largely ignored by RBV researchers despite the importance of excess capacity as a competitive factor influencing many industries (Prahalad and Hamel [1994]). One exception is Montgomery [1995] who compares the rigidities of acquiring resources to the rigidities of shedding them.

The multi-national food manufacturer was motivated to implement a model for strategic supply chain analysis because senior management recognized that total North American manufacturing capacity was in excess. The model determined, in effect, which plants had stranded product and facility sustaining resources. In this case, management's interest was to decide on which facility or facilities to close. There was no

effort made to investigate how some product markets might be expanded, thereby causing the stranded resources to be more profitably employed. Since the companies' product lines are quite mature, the decision to ignore options on the marketing and sales side of the business was probably well founded. The model also demonstrated the low marginal value of opening a new plant, a pet project of the management team in the country where the plant was to be located.

The wholesaling/retailing company developed and used a supply chain model to evaluate new designs of their distribution network. Since they took a "greenfield approach" to the location and sizing of new facilities, the supply chain model, in effect, sought to establish facilities with only heterogeneous and homogeneous resources. In studying the supply chain of the specialty chemicals company, the model consistently identified optimal strategies under a range of scenarios for which certain process sustaining resources reached their upper bounds and represented significantly heterogeneous resources. The company is investigating investment alternatives for expanding them, as well as acquisitions and joint ventures to add capacities in these categories in new locations. The firm's supply chain model will be used to study the economics of these alternatives.

The extent to which the firm's resources are heterogeneous, homogeneous, or stranded depends on the activities using them. The intersection of activities with resources was discussed in an earlier section. The schema discussed there is not intended to convey the idea that a firm can make existing activities more profitable, or create profitable new activities, in a mechanistic manner. Rather, the firm's activities reflect organizational realities within the firm and between the firm and its suppliers and customers.

For example, the new flow-through activities being investigated by the wholesaling/retailing company can be implemented only for products from suppliers who have the capability and willingness to organize and bar code their shipments by final store destination. Similarly, when considering manufacturing products in Mexico for the US and vice versa, the multinational food company must determine if plants in the respective companies can efficiently execute different product recipes for the two countries. To evaluate the introduction of a new product, the specialty chemicals company considers activities only at those production sites that have personnel with expertise in starting up new processes for products that have not previously been manufactured in large volumes.

The taxonomy in Figure 6 represents only a start at connecting data driven models with RBV. Considerable empirical and conceptual research is still needed. Empirical results from the three applications discussed above in the form of shadow prices on specific resources are not available due to the confidentiality of the data and the models. In the paragraphs that follow, we discuss briefly two central issues currently under investigation.

One central issue is: For the purposes of modeling, what is a **comprehensive set of resources** within the firm to include and how do we measure their costs? Data driven models tend to be conservative in their definition and treatment of resources. Resources in these models typically refer to physical and human resources such as raw materials, machine capacities, facility capacities, and labor. On the other hand, RBV has thus far considered resources exclusively from a qualitative, theoretical perspective, including invisible resources such as managerial expertise (Castanias and Helfat [1991]) and corporate knowledge (von Krogh, Roos and Slocum [1994]). The challenge is to use

concepts from RBV in extending data driven models to include less tangible but still measurable resources.

Following Daft [1983], Barney [1991; p 101] states that the firm's resources "include all assets, capabilities, organizational processes, firm attributes, information, knowledge, etc., controlled by a firm that enable the firm to conceive of and implement strategies that improve its efficiency and effectiveness." Barney goes on to suggest that the firm's resources can be classified into three categories:

- Physical capital resources – the firm's facilities, equipment and physical technologies; the location of facilities; and the firm's access to raw materials.
- Human capital resources – the training, experience, abilities and relationships among individual managers and workers in the firm.
- Organizational capital resources – include the firm's reporting structure, its formal and informal planning and control systems, and formal and informal relationships with individuals and organizations outside the firm.

Data driven models can readily incorporate physical capital resources. They can also incorporate certain categories of human capital resources as they relate to aggregate, measurable quantities of labor (e.g., skilled machinist hours available for the coming year). Human capital resources as they relate to individual managers and workers in the firm can, in principle, be implicitly represented in models by the costs and parameters associated with transformation activities in which these managers and workers participate. Nevertheless, research is needed to more completely incorporate human capital resources in data driven models, especially as they relate to new product developments and to demand side activities such as marketing and sales.

The incorporation of organizational capital resources in data driven models is in part a tautological issue since models are intended to improve formal planning and control within the firm. Data driven models and decision support systems offer the promise of sustained competitive advantage to any firm that is able to embed such systems in their formal planning procedures. These developments have only just begun to appear in selected companies. Studying the synergy between decision support systems and heterogeneous organizational resources is an important new area of research.

The second central issue in connecting data driven models of the RBV is the **scope of the models**. The applications discussed above were not unambitious in their scope. Nevertheless, important expansions were possible, especially to address the acquisition and allocation of heterogeneous resources permitting the firm to achieve a *sustained* competitive advantage.

The directions of expansion include

- models that capture more of the supply chain
- models that maximize net revenues by varying product mix rather than minimizing the total cost of meeting fixed and given demand
- models that link supply chain strategies with new product and marketing strategies
- models that address multiple time periods
- models that explicitly address strategic uncertainties

Clearly, a model that optimizes a snapshot (single period) description of the firm's supply chain for a single product line by minimizing the cost of meeting fixed demand for the line over the period does not provide sufficient information to conclude that certain resources are strongly heterogeneous or strongly stranded in a long term strategic sense. Dynamic, multi-period models are needed to evaluate major resource acquisition and utilization strategies. The analysis model depicted in Figure 6 from a snapshot would be used to suggest potential new resources to consider in extended models. Such models must be carefully constructed to capture the complex relationships among resource acquisition decisions that almost surely will exist. Black and Boal [1994] discuss these inter-relationships and the dynamics of resource acquisition strategies that the firm should follow.

If the scope of a supply chain model is sufficiently large, one can argue that strongly heterogeneous resources, along with production activities that utilize them, are core competencies of the firm. Data driven models of the type we have been discussing can be used to investigate options for increasing the available quantities of such resources and for creating new products from production activities that employ them. An interesting research question is: Can all of the firm's core competencies be identified and studied in this way, or are some core competencies inherently qualitative and cannot be represented in a data driven model?

Finally, a deterministic model, even one that maximizes the discounted sum of net revenues over a multiple period planning horizon, might fail to identify resources that allow the firm to successfully hedge against major sources of uncertainty. As discussed above, stochastic programming models that simultaneously treat multiple scenarios of the future are well suited to this task. Moreover, stochastic programming models can identify scenarios and contingency plans under which key resources will be heterogeneous, homogeneous, and stranded.

Space does not permit us to discuss these model extensions in depth. Their development involves the blending of modeling principles with concepts from RBV. They will be addressed in a subsequent paper (Shapiro [1995]).

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